THE BEST LAID PLANS OF MICE AND MEN AND MACHINES


The best laid plans of mice and men and machines

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South Africa’s large underground mines, containing some US$2.5 trillion worth of metals and minerals, are complex systems characterized by underground geological/geotechnical uncertainties, risks, and high process variability. System variability makes plans uncertain and business more vulnerable. Commodity price fluctuations, rising costs, and labour unrest have affected the sustainability of operations and put into doubt the economic viability of mining this national asset.

Current planning software, generally based on averages and simplified mining processes, gives little indication of the probability and range of possible outcomes of a plan, or the risks associated with a plan. Separate technical planning tools and planning processes used along the value chain are not always well integrated and coordinated. Similarly, the technical tactical and operational systems and processes are not always well integrated with strategic and enterprise resource planning systems.

The new wave of mechanization, automation, and robotics being driven of late in the Gold and Platinum sectors, requires commensurate mechanized, automated, and robotic planning (and control) systems. Simulation-based planning ‘machines’ could help improve the designs and plans of mining, engineering, logistics, and other value chain systems. Plans and systems are meaningless without business processes and people committed to their diligent execution. The more complex the system the greater commitment and diligence are required.

Whilst simulation- and risk-based planning systems are indispensable in the manufacturing, aerospace, and defence industries, the constantly changing configuration of large underground mines presents unique challenges to this technology. The Centre for Mechanised Mining Systems (CMMS) has progressed on the development of a simulation- and risk-based mine planning tool to help design, plan, optimize, and control the key technical system processes involved in the mining value chain.

This is the first paper that introduces some of the concepts around which a technical planning system is being designed and built. The paper discusses perceived mine planning needs and some CMMS challenges in developing a more mechanized ‘planning machine’ to address future mechanized mining systems Development is initially focused on a tactical and operational simulator. Subsequent development of a strategic tool is envisaged, that will characterize detailed tactical-resolution mine models into suitable strategic models.

Introduction

The mining industry is struggling to contend with challenges. In 2012, global mining net profits declined by 49% and for only the second time in the past decade there was no increase in mining revenue. PriceWaterhouse-Coopers (2013) reported that ‘the first four months of 2013 have been tougher than at any time in the past decade’ with the market values of 37 of the top 40 mining companies decreasing by 18% because the market lost confidence in the mining sector’s ability to control costs and deliver on promises. All this while production volumes increased by only 6% in 2012 because operating costs were outgrowing production. The productivity performance from 2012 has, of course, been further exacerbated by the turmoil in the Platinum sector in the 2013/14 period.

Some industry commentators say that the golden age of mining in South Africa may be over. Gone are the days when simplistic plans will automatically generate profits. This is a somewhat simplistic view as Figure 1 indicates that mining remains a valuable contributor to the economy.

Figure 1. Mining Contribution over the last 10 years
however, the make-up of the resource types has changed dramatically as indicated in Figures 2 and 3. Nonetheless, various compounding effects still threaten the industry. The depletion of easy-access high-grade reserves are driving mines deeper and access further, leading to increased power and other costs. Depth and distance increases safety and health risk. Labour expectations, work stoppages, and adverse commodity price add to the challenges. The list is not exhaustive, but seeks rather to illustrate that there are many variables and many possible scenarios in any mine plan.

A mine plan can become obsolete very quickly as circumstances and events change. Mining is characterized by risks, variability, and uncertainty. There is a need for planning to reflect these characteristics more at strategic, tactical, and operational planning levels. Margins for error are reducing and planning needs to become more detailed, comprehensive, and responsive to change.

The paper will discuss the authors’ perceptions on the need for improved mine planning systems in the context of South Africa’s large underground gold and platinum mines. This mining sector was chosen as its value chain involves complex engineering and mining, ore handling, logistics, mechanization, and other systems that can benefit from simulation- and risk-based planning and optimization technologies. Particular focus is placed on the low-level technical-related design and planning systems (tactical and operational) rather than enterprise and strategic planning systems (strategic). The paper also discusses some aspects of research and development into systems modelling software and simulation- and risk-based planning software at the Centre for Mechanised Mining Systems (CMMS) based at the University of the Witwatersrand (Wits).

The need for improved mine planning systems
South Africa’s large underground mines are complex systems subject to the internal and external risks and uncertainties described above. This section discusses what is needed to improve the effectiveness and efficiency of current planning-related processes and tools.

Integration of value chain processes
The current planning process is very people-intensive. Budget and monthly planning requires interactions with survey, geology, engineering infrastructure, ventilation and cooling, plant, labour procurement, maintenance, mine departments, and head office.

Many disparate technical software applications address planning (and design) aspects of the mining value chain. The specialist technical nature and independent development of these applications results in time-consuming imports, exports, and feedback between multiple-truth databases and people in different departments. The problem extends across the value chain systems and between different levels of planning (strategic, tactical, and operational). The planning cycles, time windows, and current tools limit the ability to investigate alternative scenarios, designs, plans, and risk-assessment, and limit response time to changes in circumstances. Planning response times and detail are especially important in highly volatile environments such as mining. The authors believe there is a need for an integrated, flexible planning tool that addresses key systems across the value chain and provides appropriate resolution at operational, tactical, and strategic planning levels.

Managing risk and uncertainty
Most technical mine planning systems do not address risk management. Apart from the obvious risks to people mining at depth, there are many mining, support system, and external environmental risks that can affect plans. Planning generally works with average advance rates and durations. Many of the uncertainties and risk events lie in the deeper level detail of mine processes and in the shorter intervals of time. Simulation models address this requirement better than scheduling tools.

The authors believe that risk management should be a key component of a planning tool. Risk has a downside, and an upside called opportunity. Forewarned is forearmed. Identified opportunities can be exploited, and risks transferred, avoided, accepted, or acted upon. Methods such as Failure Modes, Effects and Criticality Analysis (FMECA) are commonly used but these approaches cannot predict the combined effects of risks and uncertainty in a system as well as simulators can. This often leads to large and unexpected discrepancies between predicted schedules and actual performance.

Simulation- and risk-based planning cannot predict future
realities but it can produce plans that are more realistic. It also provides an indication of the likelihood of a range of possible plans and scenarios. Perhaps more importantly, simulation indicates how robust a plan is, i.e., its sensitivity to uncertainties, risks, assumptions, project configurations, design parameters, technology changes, etc.

For example, the Platinum industry break even analysis shown in Figure 4 clearly indicates that older labour intensive mines are not competitive with newer mechanised operations. In order to survive and extract an optimal life from the older set of mines requires a sophisticated analytical approach to test operational scenarios on an ongoing. In this way, new configurations, technologies and labour practices can be combined for improved financial performance.

Increasing resolution and scope of planning models
Current mine scheduling, from a business process point of view, treats mining processes at a relatively high level. Current tools have to make simplifying assumptions about the capacities and performance of underlying mining, engineering, logistics, and other systems. Current planning models are simply not detailed enough to consider many of the factors and variables in the next levels of process activity.

Higher resolution planning requires a more holistic ‘system-of-systems’ view of the value chain and the interdependencies between systems. Current planning tools integrate geology, mine design, planning, and survey – at a coarse process level of planning detail. The authors believe that better plans will result if interrelated systems are simulated together (power, water, ventilation, refrigeration, logistics, service departments, beneficiation, economics etc.).

Simulation-based planning works with a greater level of systems detail and smaller time increments than mine scheduling. Simulators are expensive and time-consuming to build and maintain in a package like Arena. Consultants or specialist groups in large mining companies generally do simulation work as once-off projects. An ongoing simulation-based planning tool requires a different approach.

Management of system knowledge and information
Sustainably capturing and updating knowledge and information required for simulation is a challenge. Hattingh and Keys (2010) examined the applicability of industrial engineering to mining. Holton and Porter (2012) examined the success of systems engineering in aerospace and defence systems and its applicability to mining mechanization. There is growing acceptance of these disciplines and the use of Toyota Production Systems (TPS), Lean, Six Sigma, Theory of Constraints, and broader systems engineering practices for systems design and improvement.

Significant undocumented knowledge and information about the detailed workings of mine systems resides in the headspace of workers at all levels. This is a valuable asset, which is often degraded through employment turnover and restructuring. Fortunately, mining, like most industries, is beginning to employ industrial and systems engineering disciplines to help understand and improve its business processes. This will contribute to the knowledge and information required for simulation-based planning.

A well-structured simulation-based planning tool is a sustainable and re-usable knowledge base for mining systems knowledge and information. The authors believe that simulation-based planning provides added incentive to better manage mining business processes. A learning organization requires a tool for teaching and training. A simulator can be used to create situations and scenarios for training management and predicting the causal effects of their decisions at different levels of the organization.

Business process interdependence, engineering, and planning
Current planning systems cannot easily predict where and when infrastructure and support system constraints are exceeded. Current planning models do not incorporate engineering system models (water supply and drainage, compressed air, ventilation, power, ore flow, heat flow, logistics of people, materials, and machines. Lost-production events occur for a variety of reasons such as a lack of water supply or pressure, ventilation, power, ore storage etc... The authors believe that a holistic simulation-
based planning tool will identify many such problems at the planning stage. Prevention is better than cure.

Many new-technology mechanized and other mining systems tested at pilot sites in the past failed unnecessarily. Opportunity was lost because technologies, environments, location, support systems, and processes were not ideal and did not provide a successful proof of concept. Failure was almost inevitable in many cases. Detailed simulation- and risk-based planning provides a viable alternative for testing and trialling new systems.

**Real-time planning and control**
The digital revolution is extending the Internet and intranet to underground workplaces. This presents opportunities to monitor and control the processes and activities of people, mechanized machines, and engineering support services. Modern process plants exploit high-tech information and computer technology (ICT) where SCADA (supervisory control and data acquisition) and advanced control help people to manage systems in real time.

In almost every sphere of human activity, machines are relieving humans of intelligent and routine activities and perform them faster, more consistently, and more reliably. An ideal mine simulator equipped with knowledge of the mining systems processes, the current state, and desired (planned) state will help planners respond in an optimal way to address unexpected events and changes – as decision support tools and automation where it is safe and sensible.

**Summary of needs**
In summary, the authors believe there is a need for a realistic 'mine simulator'. A simulation- and risk-based planning tool is envisaged that is capable of detailed modelling (mimicking) of key elements of the technical mining systems processes, the current state, and desired future state. A simulation- and risk-based planning tool will identify many such problems at the planning stage. Prevention is better than cure.

In almost every sphere of human activity, machines are relieving humans of intelligent and routine activities and perform them faster, more consistently, and more reliably. An ideal mine simulator equipped with knowledge of the mining systems processes, the current state, and desired (planned) state will help planners respond in an optimal way to address unexpected events and changes – as decision support tools and automation where it is safe and sensible.

Some potential benefits include:
- Faster and more accurate scenario assessments and production of detailed plans
- Balanced design with planning across the value chain
- Confidence in plans based on engineering and process knowledge
- Assessing sensitivity to stakeholder uncertainties and risk perceptions
- Sustainable and re-usable systems process knowledge and information
- Exploitation of advances in underground communications and mechanization
- Real-time monitoring and advanced control of value chain systems
- Exploiting the computing power of multi-core processors and supercomputers
- Exploiting developments in simulation-based planning optimization
- Freeing up planners and engineers from routine design and planning processes.

**Research and development towards an improved planning system**
The new wave of mechanization, automation, robotics, and communications technology requires commensurate mechanized, automated, and robotic planning (and control) systems. We believe a sustainable mining simulation technology is the starting point for improved design and planning.

The CMMS has progressed on the development of a simulation- and risk-based mining planning tool to address some of the mining needs discussed above. The simulator will help model, plan, optimize, and control the key technical system processes involved in the mining value chain. Particular focus is on large tabular underground mines where various geological, mining, engineering, and processing systems interrelate in particularly complex ways. Some of the CMMS challenges and solutions are discussed below.

**Mining for knowledge in complex systems**
Simulators are as good as the knowledge and information built into them. Mining for this is often more difficult than mining for the minerals. The CMMS recognizes that the most important processes in conventional and mechanized mining are the ones that involve people. Furthermore, mining people possess the knowledge, and need to be satisfied that a simulator reflects their understanding and can be trusted to do the same or better than they can with other tools.

People do not readily trust ‘black boxes’. Business process management aims to ensure that all things work together effectively. The CMMS method is to first describe and verify system processes before creating simulation building-blocks. This is achieved with a novel CMMS software tool that captures stakeholder knowledge and information into a process-oriented knowledge base. The tool automatically generates WYSIWYG stakeholder views of system process circuitry. The views help technical and non-technical stakeholders gain an understanding by looking at high-level processes, flows, and drill down through levels of processes into the activity logic level inside processes.

Activities within process boxes are the atoms of systems and simulators. Activities show the sequence of steps and required inputs (of data, resources, or anything else) required to perform an activity, and the resultant (process) outputs from activities.

There are many ways to group and describe the value chain and life cycle processes of mining. This has been a source of confusion to mining, IT, and other technology stakeholders. The CMMS adopted the recently released Exploration and Mining Business Reference Model (EM Model) released as an Open Group Technical Standard. This EM Model is a process framework produced by the Exploration, Mining, Metals and Minerals (EMMM) Forum with the support of several large mining, IT, and consulting companies.

The CMMS has developed example template systems for a couple of mining methods using the EM Model. The EM Model describes only a few levels of generic mining processes (See Figure 5). The templates required three or four additional levels of process-in-process detail for simulation purposes.

Understanding complex mining system circuitry composed of thousands of processes and interrelated flows is not easy. A picture tells a thousand words. The system circuit diagrams holistically display both ‘softer’ people processes, and ‘harder’ processes relevant to simulation. Detailed circuit diagrams are large, complex, and can become confusing. Comprehension and learning require different levels of detail in different parts of a system at
different times. The ‘Goldilocks’ principle of not too much and not too little applies. Different level diagrams quickly loose integrity after editing with simple process drawing software like Visio or CAD (See Figure 6).

The problem of generating system diagrams using the different levels of detail from a single knowledge base prompted CMMS to sponsor the development of a computer-aided tool. Rules ensure that system knowledge and information is captured into a knowledge base, which has integrity. The tool automatically generates circuit diagrams to suit stakeholder perspectives. The circuit diagrams help stakeholders verify their own systems and understand relationships with other interrelated systems.

Re-usable building blocks of mining systems
The system circuit diagrams help stakeholders identify repeat process patterns that constitute the re-usable building blocks of simulation models. One–to-one correspondence between the stakeholder-identified processes (in system process diagrams) and simulation process objects provides integrity and trust between stakeholders and simulation builders and mutual trust in the simulator.

Re-usable simulation objects are pre-built from the stakeholder system diagrams. Once-off and custom processes will also be required, but the simulator’s powerful graphic/visual programming facility makes this easier than writing computer software code.

Using a standard simulation package is too slow and would be analogous to using AutoCAD for mine planning. The mine simulation model, largely built and maintained automatically, achieves speed and integrity. The simulation model is created from different sources: from the stakeholders’ system circuit diagram (knowledge base); from geological mine-planning models (database); from various engineering application models (databases). The framework also provides for creating re-usable intelligent stakeholder process models that, for example, design and extend engineering infrastructure or optimize plans within infrastructure constraints using operations research techniques.

In summary, breaking down system complexity into process objects with encapsulated activity knowledge and interconnected flows between other objects is a natural and robust way to understand (and mimic) real-world systems. This approach will hopefully reduce the natural distrust of black-box simulation and optimisation-type tools and speed up implementation.

Computation and planning process speed
Lack of computer power has limited the extent of use of simulation for mining and other applications. Mining simulation is particularly computationally intensive due to the level of required detail, the size of systems, the smaller time steps (compared to scheduling), and the multiple runs required for risk assessment and optimization. Real-time execution and control also requires computation power to keep pace with monitored processes. Increased speed allows for more plans and scenarios to be created and evaluated during each planning window, resulting in better plans and risk/opportunity assessments.

Fortunately, processing power is still increasing exponentially. New technologies such as multi-core processors, supercomputers, and distributed computing (in the cloud) are providing a step-change improvement for all types of simulation applications. The CMMS is exploiting multi-threading simulation features and special software
customization to exploit new computational technologies.

The CMMS simulator addresses detailed real-time simulation but is ultimately intended for all levels of planning (long-term to real-time). All levels require fast processing because of the trade-off between model detail and time span. We are researching methods of characterizing higher-level (faster) models derived from many simulation runs using detailed process-level models. Computational processing power is not the current bottleneck. Planners spend (waste) significant time importing, exporting, and repeating routine operations, albeit with the aid of software tools. Modelling the value chain in one place and incorporating explicit routine design and planning logic into the simulator reduces time wastage.

We believe an integrated simulation model of value chain processes, design, and planning processes (suited to automation) will streamline planning processes and lead to the production of better plans faster.

Mining for risk information

Mining operations collect significant amounts of data. They may not have sufficient information on process and activity variation and frequencies of events specifically required for simulation. Collecting statistics for a mining simulator is time-consuming and expensive, and often unreliable as mining circumstances and locations are constantly changing.

The CMMS has adopted a different approach. Focus is rather on collecting detailed knowledge and information about how the systems work. The process-centric approach described above decomposes mining processes down to the 'atomic' activity level required for simulation. At this level, tasks and activities are simple and familiar, and enable workers or experts to provide a large number of realistic estimates of activity duration (minimum, average, and maximum) and other parameters. Alternatively, the simulator helps determine if a plan is sensitive to 'guesstimates' or robust enough not to warrant concern.

Estimates for variance of activity durations and probabilities of risk events will enable the simulator to predict the band of system behaviour and performance, and likelihood of risky events. This will enable planners to balance and assess risk-taking and opportunity-taking with trade-offs and cost benefits.

Integrating specialist technical applications

Despite the success of simulators in industries such as manufacturing, aerospace, and defence, mining presents special challenges. Technical complexity has resulted in the evolution of different analysis and simulation applications used for analysis, design, and planning of value chain systems. Most specialist applications developed by specialist companies work independently of each other.

We have opted for a best–of-breed simulation engine with 3D animation and object technology, which complements our process-object methodology. Our strategy is to use system information provided by the various technical systems where possible (geological mine planning, engineering, environmental, etc.).

The simulation system model is constantly changing because mining voids and engineering infrastructure are constantly changing. Normally, one works through the simulation software interface. We have developed an application to control the simulator and the interfaces to mine planning, engineering, and other data, and to the stakeholder’s system process design. This makes it possible to automate the creation and modification of simulation models and orchestrate other processes running in parallel.

The simulator incorporates engineering analysis and design elements because design affects capacity to supply mining demand, which in turn affects planning. The standard simulator can address ore handling but not pressure-flow networks. Pressure-driven networks play a significant role in underground mines (power, water, compressed air, ventilation, heat flow). We have developed simulation software for computing the pressures and flow rates in reticulation networks. Early tests on water reticulation have demonstrated rapid convergence and stability, which is required for real-time on/off reticulation demands by mining processes.

Conclusions

The margins for error in the mining process are reducing dramatically. Safety, economic, and other risks are increasing with depth of mining. Design and planning need to become more detailed, holistic and responsive to change. Planning-related technical software applications along the value-chain, and between strategic, tactical and operational levels are disjointed, lack resolution, and reduce the effectiveness of the planning processes.

Based on successes in manufacturing, aerospace, and defence, mining can benefit more from simulation-based technology. Mining mechanization, automation, and robotics under consideration and implementation in the Platinum mines, require better planning (design and control) systems. The CMMS is developing a planning ‘machine’ capable of working with detailed technical knowledge of mining value chain systems and performing routine design and planning processes. The tool is applicable to design, planning, risk management, and intelligent control of systems at the tactical and operational level. Characterizing detailed models will provide appropriate resolution models for tactical and strategic planning from a single-truth knowledge base.

Clearly, the work completed to date is largely theoretical with only a number of analytical and modeling tasks completed based on the theory. However, the basis of this research and development aims to addresses several industry design- and planning-related needs. These include the determination of why, where, and when systems can and cannot perform, and the likelihood of failure events and opportunities; and an improved understanding of systems behaviour and sensitivity to design, planning, and other variables (at operational, tactical and strategic levels). A training simulator for knowledge workers supports a learning organization. A mine simulator sustainably re-uses Business Process Management (BPM) knowledge base and information. Integration of different discipline models into a single-truth model enables mine planners and engineers to jointly address design and planning challenges faster and more accurately. Technology, methods, and process experiments can be trialled in a virtual-mine, reducing costly mistakes. A mine simulator provides the metrics and confidence for engineers, technologists, and management to make investment and other decisions, be they strategic, tactical, or operational.

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References


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Jim Porter is a Consulting Engineer with 37 years operational, project management and consulting experience. Jim commenced his career at AngloGold Ashanti (then a division of the Anglo plc Group) in 1977. He worked for Freegold North and Western Deep Levels, where he held a number of senior management positions including Production Manager, Project Manager and Mine Manager. During his time with AngloGold Ashanti, Jim ran several large shaft sinking projects, oversaw numerous technology and mechanisation initiatives as well as establishing a sound safety and production record. In 1997 Jim started up a mining technology focused services company for AngloGold Ashanti called MineRP Solutions (GMSI) as Managing Director and initiated its acquisition by a listed ICT services company. He led corporate outsourcing contracts and developed the strategy for the internationalisation and growth of the Group mining business. After a spell heading the Consulting group at Engineering Group TWP, in 2011 Jim started his own consulting company; Jim Porter Mining Consulting (Pty) Ltd (JPMC)